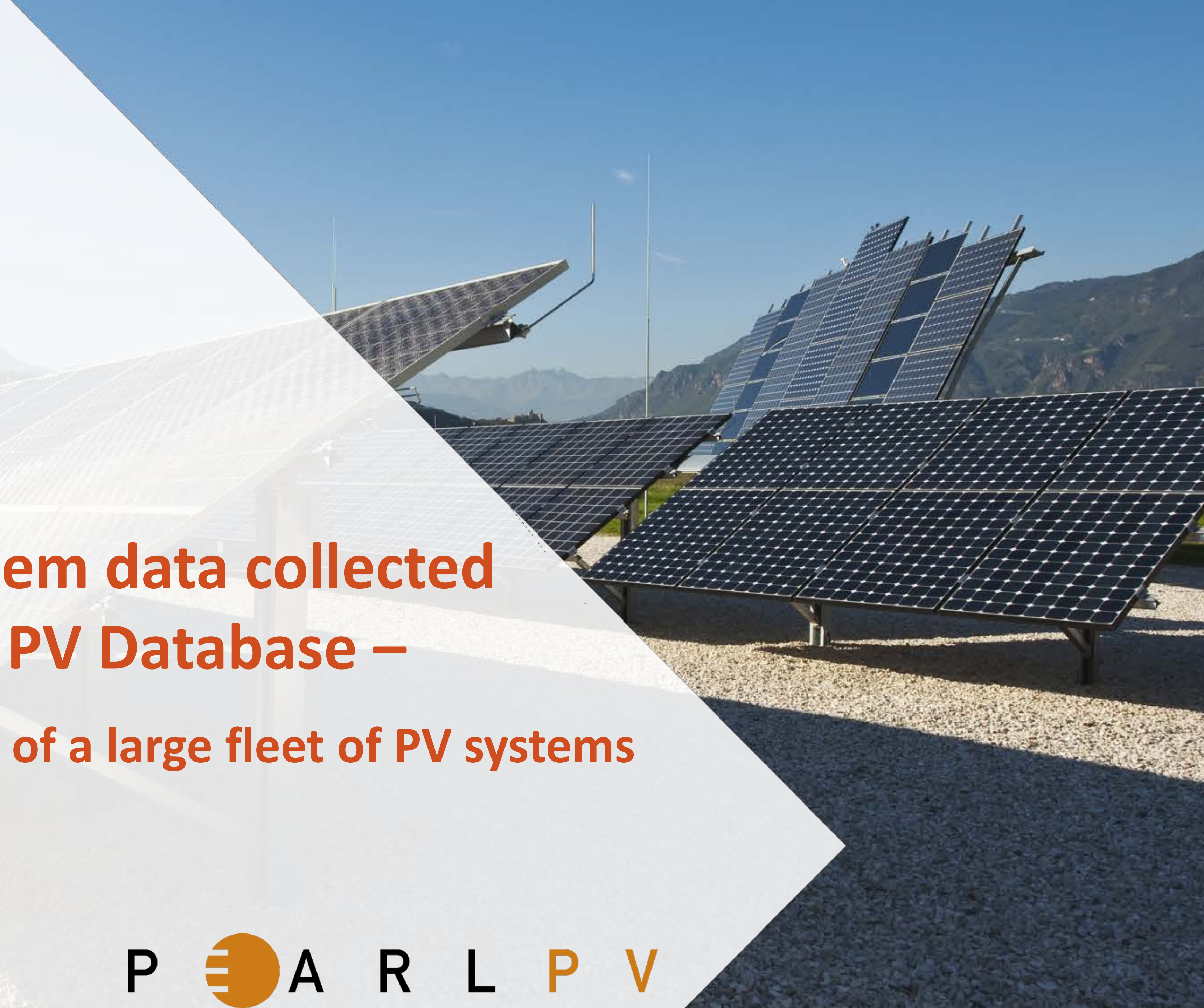
eurac research



Evaluation of PV system data collected in COST Action Pearl PV Database –

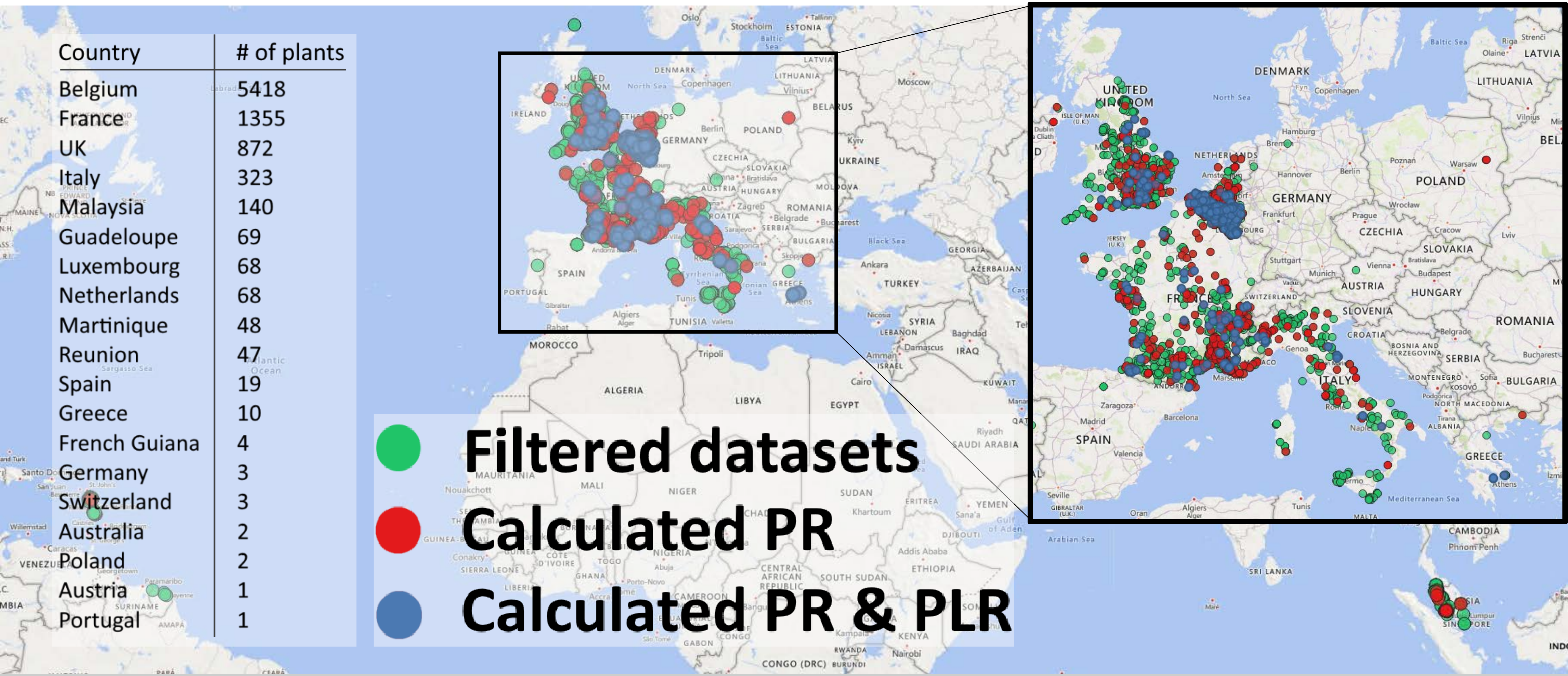
Analysis of PR, Yield & PLR of a large fleet of PV systems

Sascha Lindig
Eurac Research

PEARL PV

Overview PV systems

Country	# of plants
Belgium	5418
France	1355
UK	872
Italy	323
Malaysia	140
Guadeloupe	69
Luxembourg	68
Netherlands	68
Martinique	48
Reunion	47
Spain	19
Greece	10
French Guiana	4
Germany	3
Switzerland	3
Australia	2
Poland	2
Austria	1
Portugal	1



Initial Data Quality Grading

Letter Grade	Outliers [%]	Missing percentage [%]	Longest gap [days]
A	Below 10	Below 10	Below 15
B	10 to 20	10 to 25	15 to 30
C	20 to 30	25 to 40	30 to 90
D	Above 30	Above 40	Above 90

Pass/fail criteria	Time series > 24 months => PASS

[1] S. Lindig, et al., "International collaboration framework for the calculation of performance loss rates: Data quality, benchmarks, and trends (towards a uniform methodology)," *Progress in Photovoltaics: Research and Applications*, vol. 29, no. 6, pp. 573–602, 2021.

Initial Data Quality Grading

Letter Grade	Outliers	Missing percentage	Longest gap
A	**8,367**	**5,773**	**7,655**
B	**0**	**2,216**	**280**
C	**0**	**164**	**291**
D	**0**	**214**	**141**
D	Above 30	Above 40	Above 90

Pass/fail criteria	P: 4,323	F: 4,044

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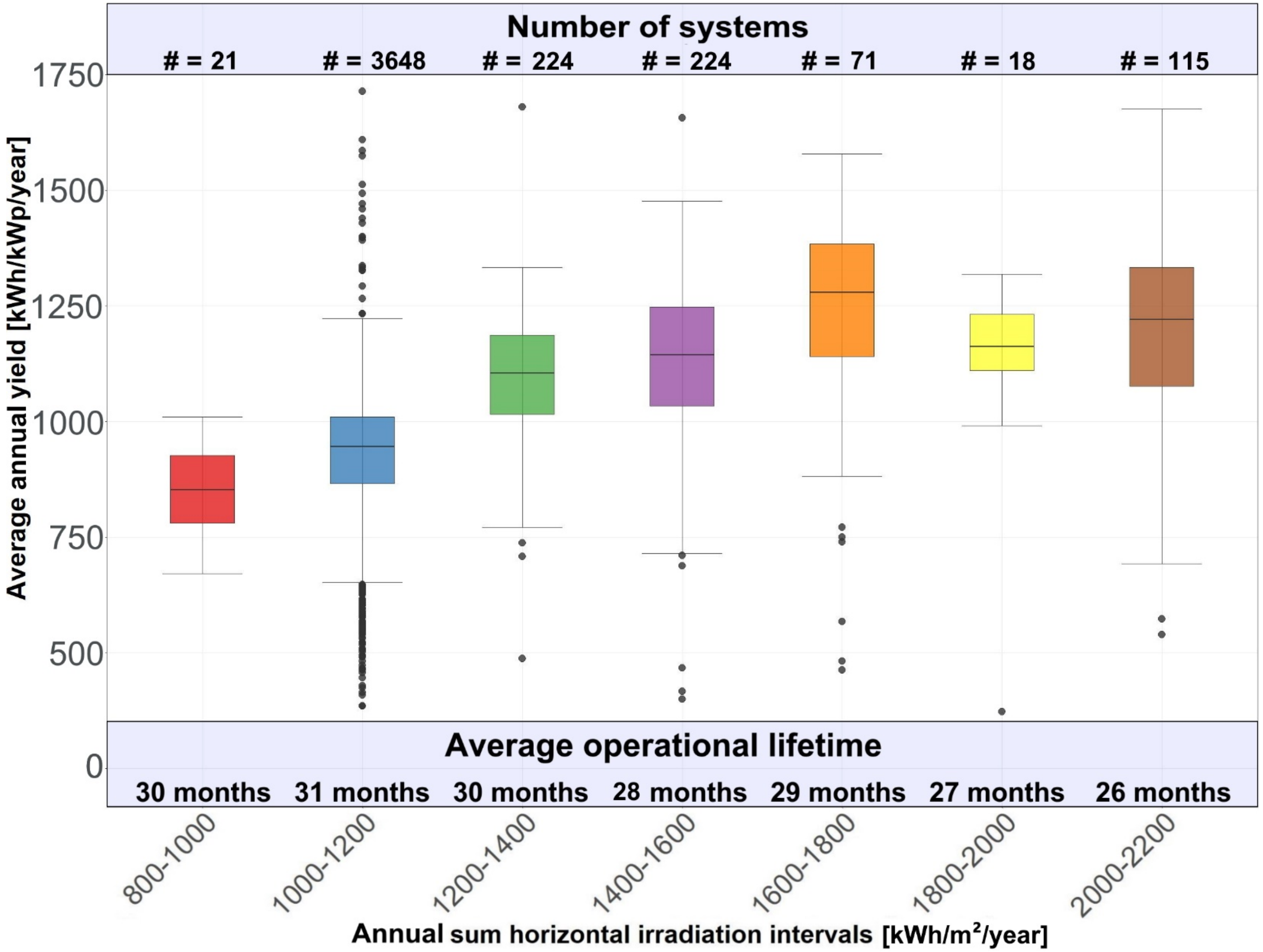
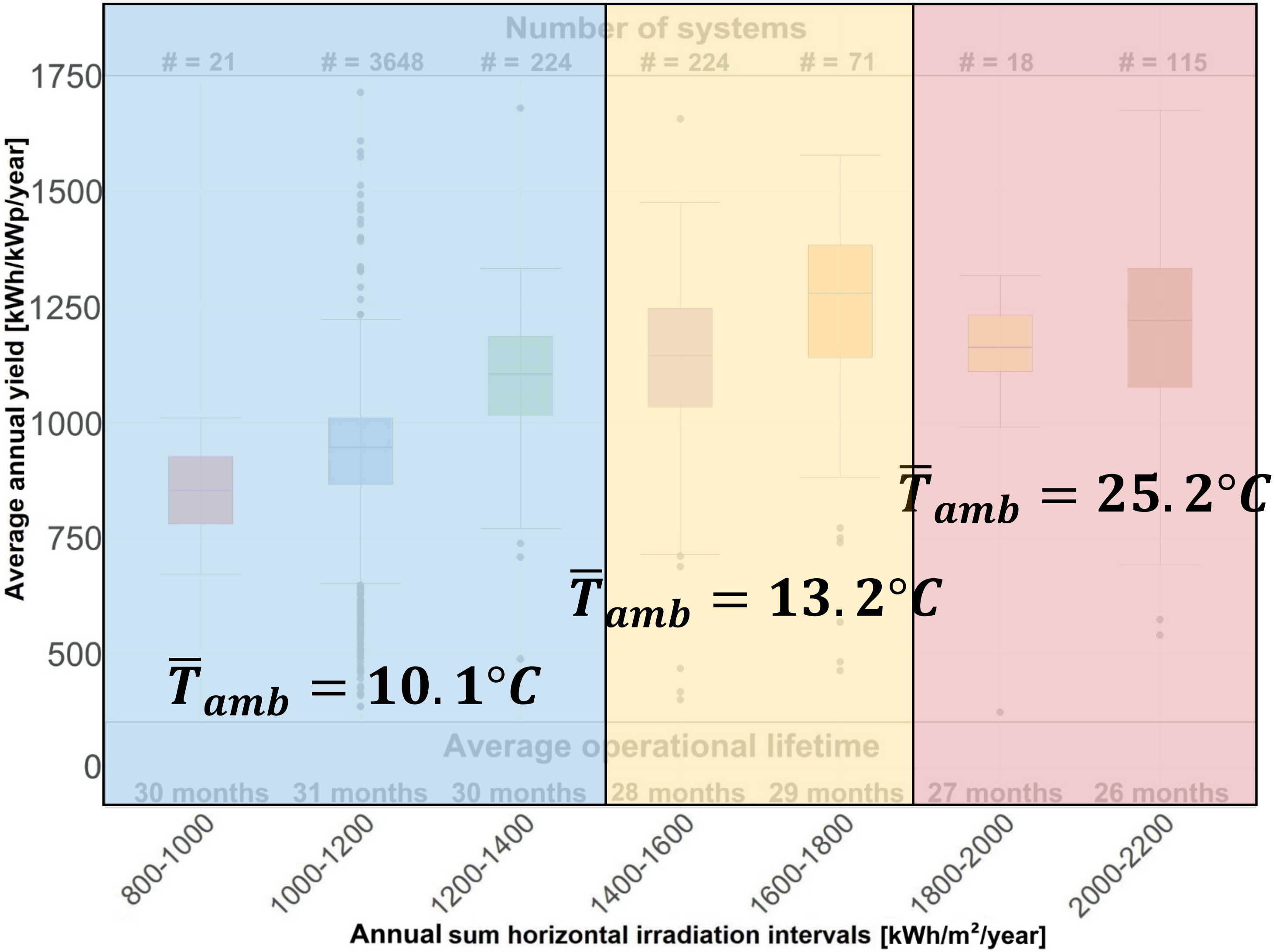
Energy Yield



$$\overline{yield} = 954.9 \frac{kWh}{kWp} \text{ per year}$$

$$\widetilde{yield} = 961.5 \frac{kWh}{kWp} \text{ per year}$$

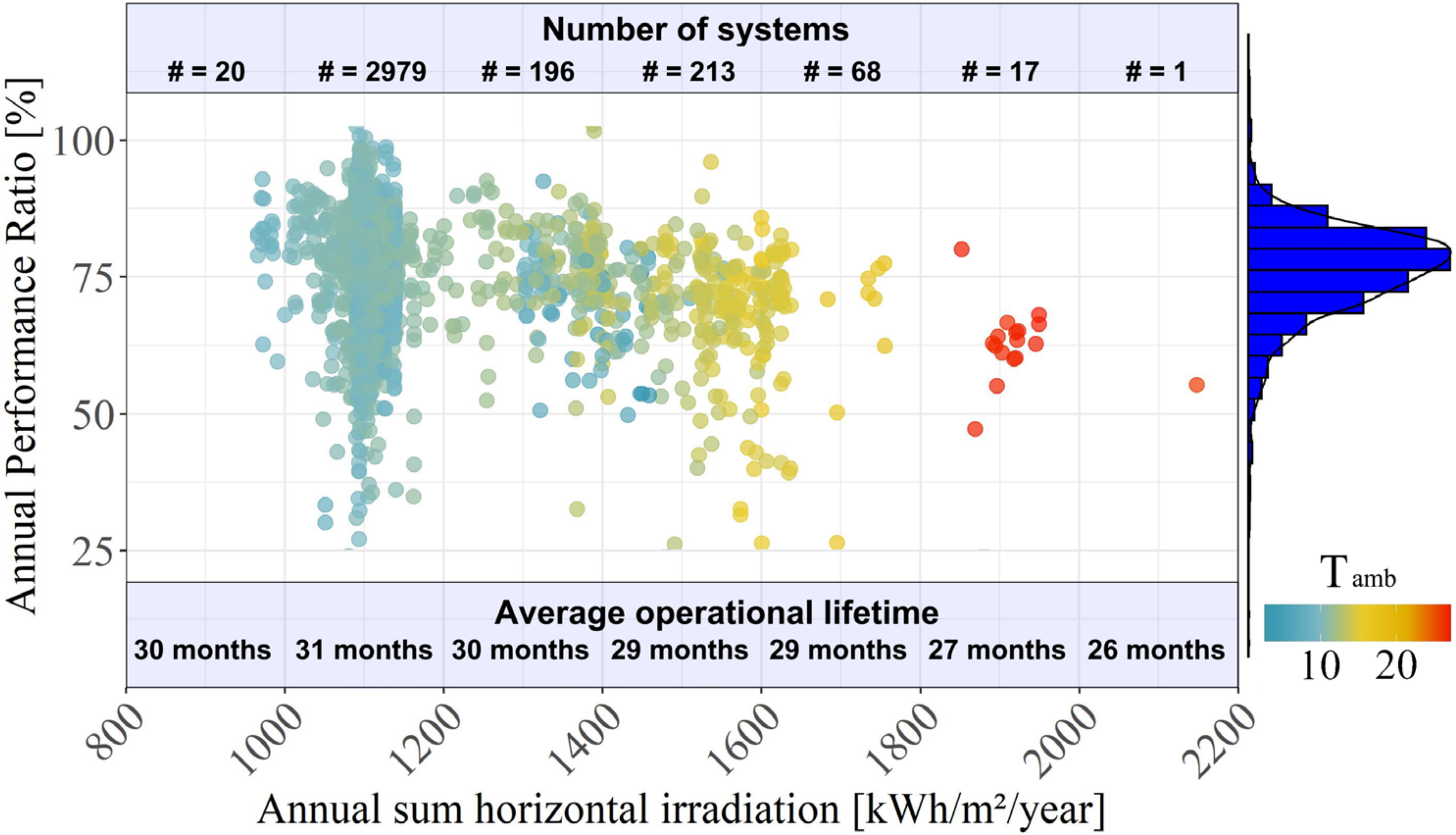
Energy Yield



$\overline{yield} = 954.9 \frac{kWh}{kWp}$ per year

$\widetilde{yield} = 961.5 \frac{kWh}{kWp}$ per year

Performance Ratio



$$\overline{PR} = 76.7\%$$

$$\widetilde{PR} = 78.4\%$$

Performance Loss Rates

0. Exploratory data analysis for data quality & grading

0.a Data availability

P_{mpp} ; G_{POA} ; T_{mod} ; T_{amb} ; $wind\ speed$

0.b Data quality assessment & grading

Outliers, missing, gaps

1. Input data cleaning/filtering

1.a Data assembly

Data imputation, Timestamp validation

1.b Filter application

P_{mpp} ; G_{POA} ; T_{mod} ; PR ; $clear\ sky$

2. Performance metric selection, corrections & aggregation

2.a Perf. Metric

Predicted Power, Performance Ratio

2.b Temp. corrections

IEC61724-1, UTC

2.c Data aggregation

Daily; weekly; monthly; yearly

3. Timeseries feature corrections

3.a Seasonal decomp.

CSD; STL; HW

3.b Imputation of

Power P; PR

3.c Outlier Removal

Z-score; Interquartile range

4. *PLR* Result

4.a Statistical models

Regression; YoY; CPLR

4.b $\overline{PLR}$ Determination

4.c Assess Confid. Int.

P_{mpp} – PV power in the maximum power point
G_{POA} – irradiance in the plane of array
T_{mod} – module temperature
T_{amb} – ambient temperature
PR – Performance Ratio

[1] S. Lindig, et al., "International collaboration framework for the calculation of performance loss rates: Data quality, benchmarks, and trends (towards a uniform methodology)," *Progress in Photovoltaics: Research and Applications*, vol. 29, no. 6, pp. 573–602, 2021.

Performance Loss Rates

Data input & Data quality analysis

- 10 min power time series
- Hourly ERA5 in-plane irradiation[2]

Input data cleaning & filtering

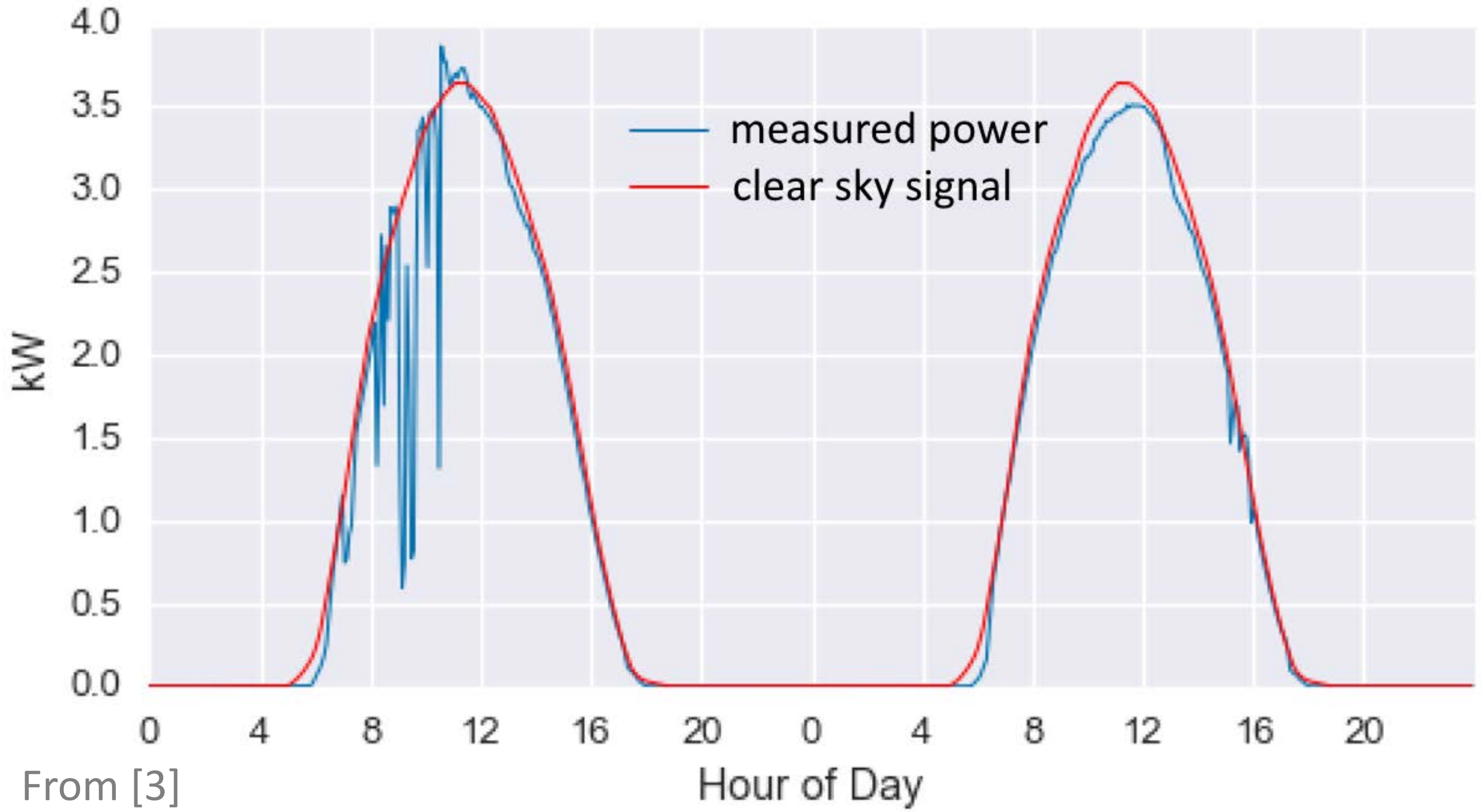
- SCSF[3] : Clear-sky filter
- YoY : Filter provided by RdTools[4,5]
- STL : Tailored threshold & statistical filter

Selection performance metric & statistical model

- Daily clear-sky energy : SCSF[3]
- Daily normalized energy : YoY[5]
- Monthly PR : STL[6]

[2] Copernicus Climate Change Service (C3S) ERA5: Fifth generation of ECMWF atmospheric reanalyses of the global climate. Copernicus Climate Change Service CDS 2017.
[3] B. Meyers, et al, "Signal Processing on PV Time-Series Data: Robust Degradation Analysis Without Physical Models," *IEEE Journal of Photovoltaics,* 2019.
[4] RdTools, “Version 2.0.5.” [Online]. Available: https://github.com/NREL/rdtools
[5] D. Jordan, et al, "Robust PV Degradation Methodology and Application," *IEEE Journal of Photovoltaics*, 2017.
[6] R. B. Cleveland et al., "STL: A Seasonal-Trend Decomposition Procedure Based on LOESS," *Journal of Official Statistics,* 1990.

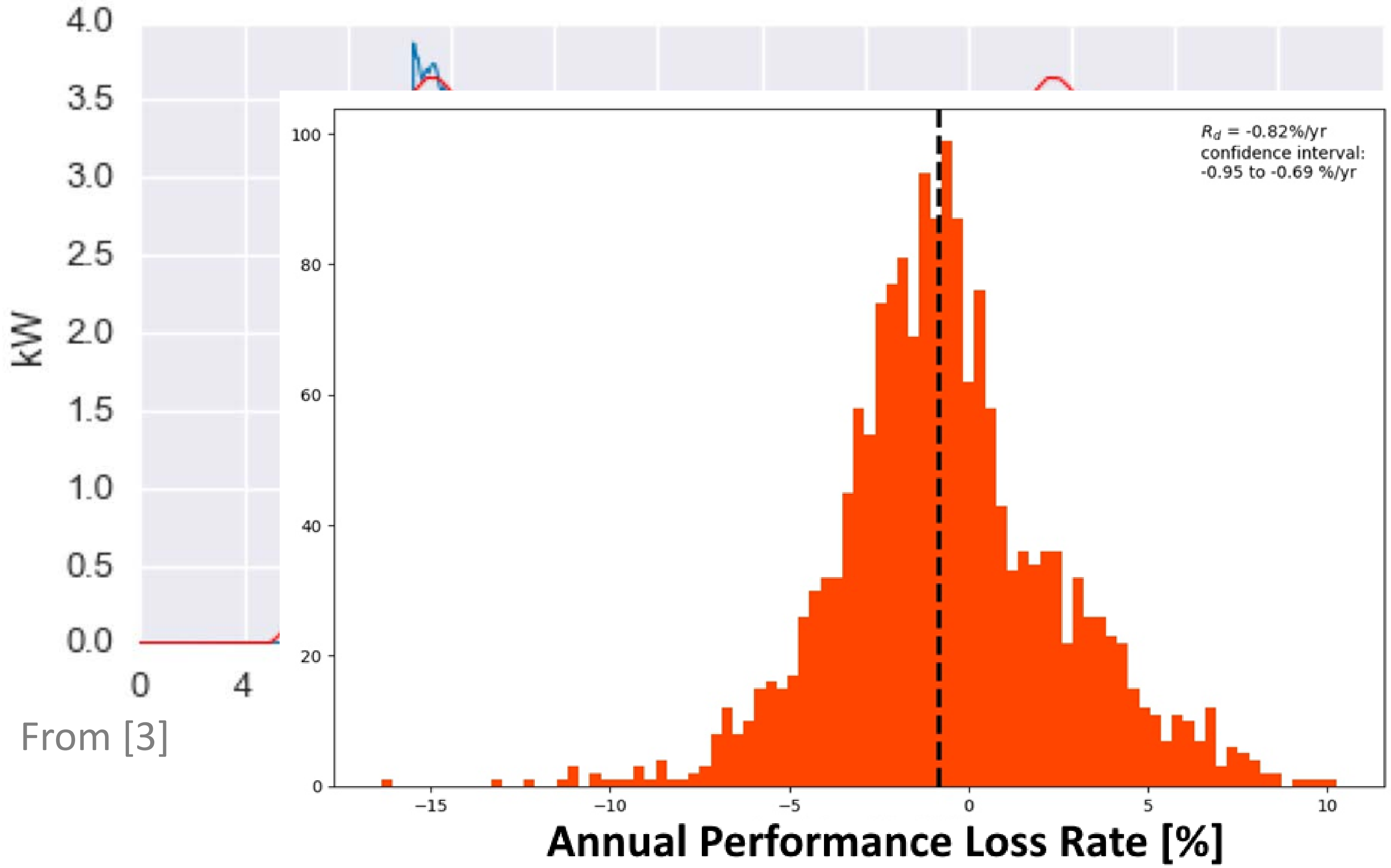
Performance Loss Rates



From [3]

[3] B. Meyers, et al, "Signal Processing on PV Time-Series Data: Robust Degradation Analysis Without Physical Models," *IEEE Journal of Photovoltaics,* 2019.

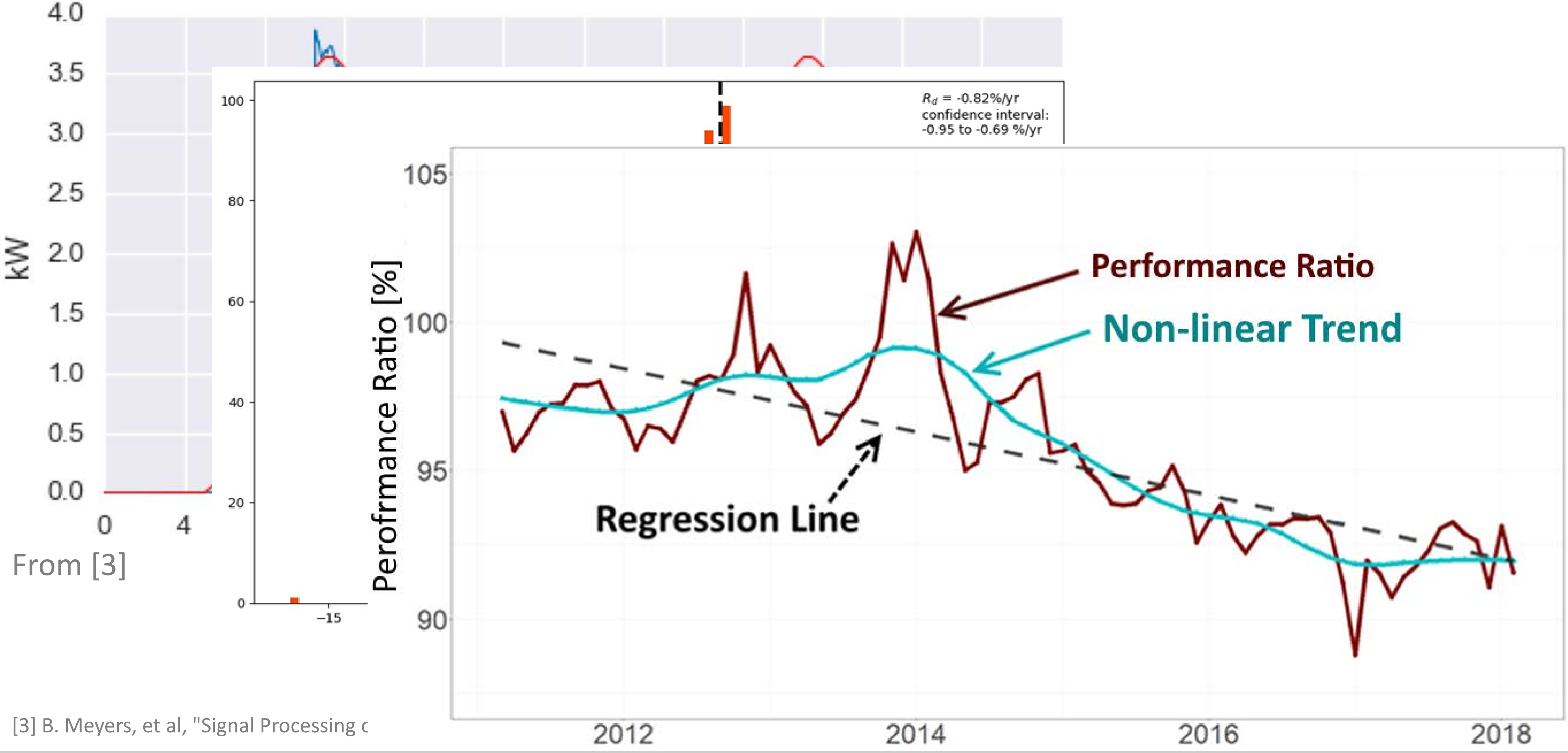
Performance Loss Rates



From [3]

[3] B. Meyers, et al, "Signal Processing on PV Time-Series Data: Robust Degradation Analysis Without Physical Models," *IEEE Journal of Photovoltaics,* 2019.

Performance Loss Rates



From [3]

[3] B. Meyers, et al, "Signal Processing c

Performance Loss Rates

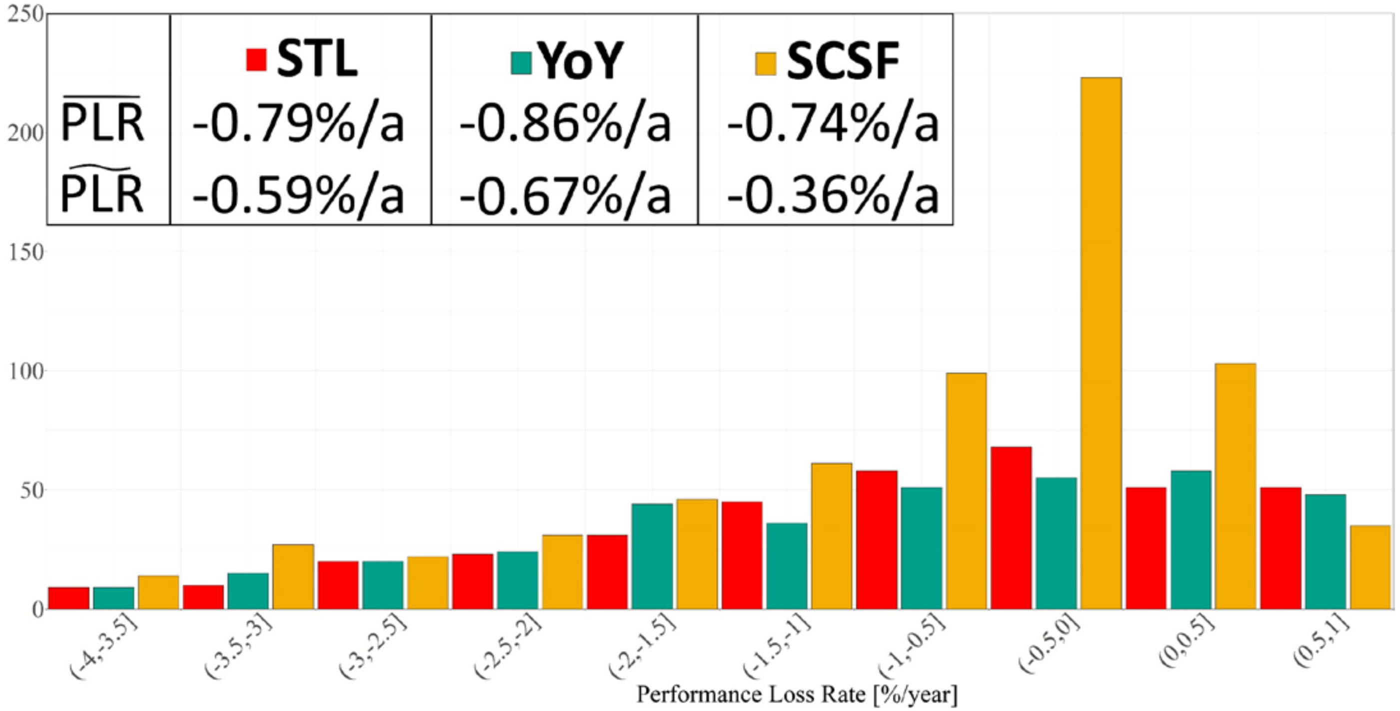
	Filter			
Statistical method	**G_{POA} [W/m²]**	**T_{mod} [°C]**	**Power**	**Performance Ratio**
SCSF	Strict clear-sky filter			
YoY	200-1200	-50 – 110	P > 0	
STL	100-1200		$(0.01 - 1.05) * P_{nom}$	$\pm 2\sigma$ around daily mean PR

	SCSF	YoY–ERA5	STL–ERA5
All systems	8,367		
FINAL	**661**	**361**	**366**

Minimum 3 years of data

-4%/a < PLR < 1%/a

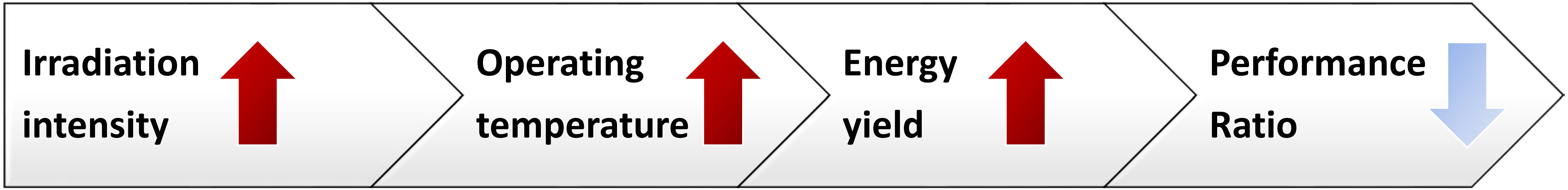
Performance Loss Rates



	Jordan[7]	Kiefer[8]
$\overline{PLR}$	-0.8 to -0.9 %/a	-0.7 %/a
$\widetilde{PLR}$	-0.5 to -0.6 %/a	

[7] D. C. Jordan, et al, "Compendium of photovoltaic degradation rates," *Progress in Photovoltaics Research and Application*, vol. 24, no. 7, pp. 978-980, 2016.
[8] K. Kiefer, et al, "Degradation in PV Power Plants: Theory and Practice," in *36th EU PVSEC, Marseille*, 2019.

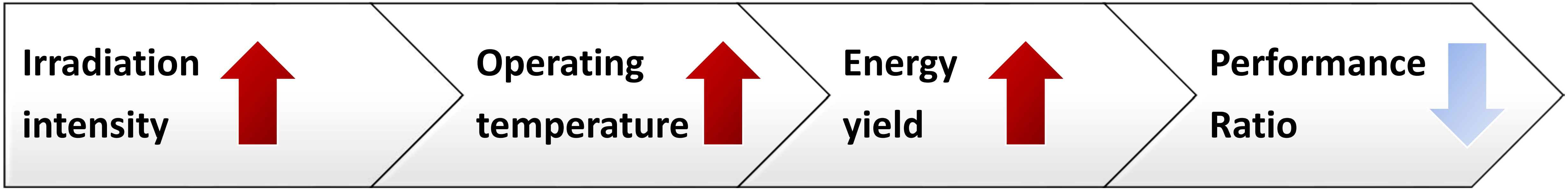
Conclusion



PLR is an important parameter to assess the **health status of a PV system**

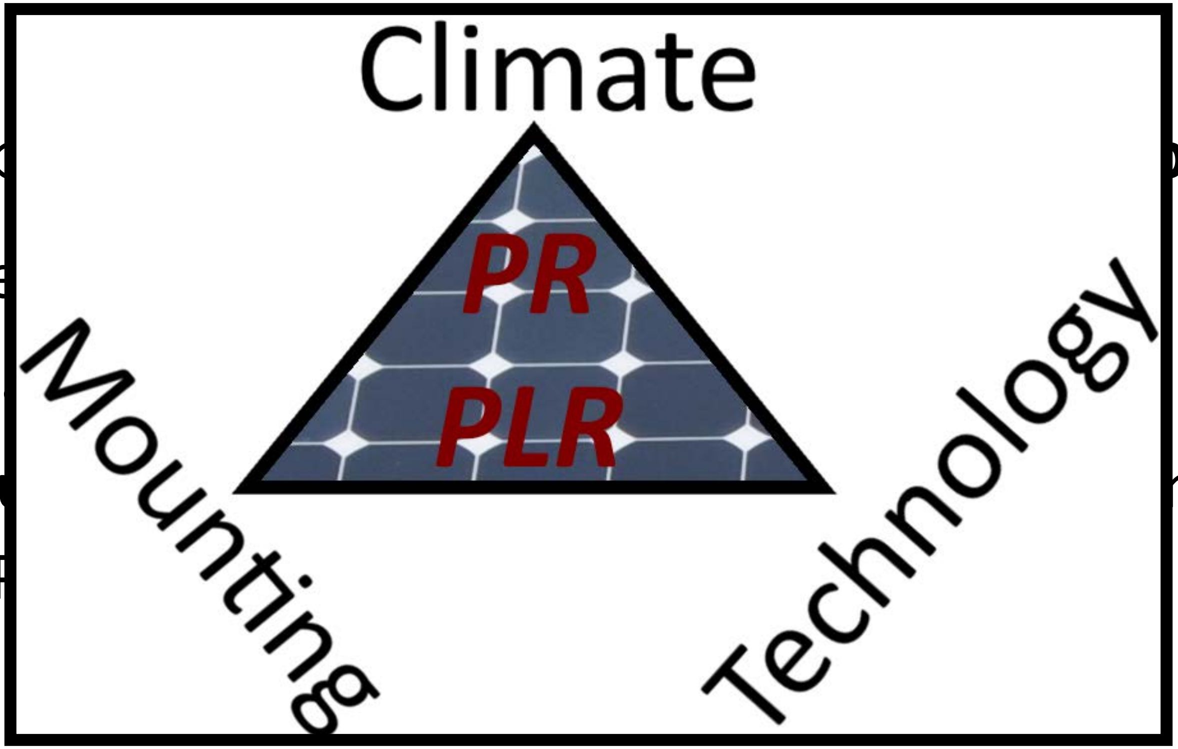
- Calculating PLR values is not straightforward
  - Many variables have to be considered
  - The length and quality of the PV system time series is the most important characteristic of PV performance analyses

Conclusion



PLR is an important p… **…of a PV system**

- Calculating PLR value…
  - Many variables h…
  - The length and qu… …most important characteristic of P…



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Thank you for your attention

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